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PERFORMANCE EVALUATION OF MULTIPLE POINT SOURCE COMPLEX (MPC - SP) MODEL FOR NORTH – CHENNAI AIR BASIN IN CHENNAI

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ABSTRACT

A self -designed computer aided Gaussian dispersion model, namelyMultiple Point source Complex (MPC)model- short term period (MPC-SP)has been evolved and it is used for predicting the GLCs of short-term SO_2 concentrations in the ambient environment of North Chennai Air Basin.

KEYWORDS: MPC – SP, Ground level concentrations (GLCs), Ambient Environment, Dispersion

1. INTRODUCTION

Industrial areas, in the contemporary India, experience a profound change in the nature and extent of air pollution. Factors, such as industrial expansion, accelerated consumption of products, fuels and energy, the introduction of hew chemical processing industries the vastly increased use of automobiles and growth of urbanization, have all greatly increased the varieties and volumes of pollutants thereby presenting new threats to the human health, animal health, plant life, property value and the environment. However, a sporadic development of industries has sprung up in the neighbourhood of residential areas in India. As a result, magnitude and severity of air pollution problems have been attracted by the attention of the public. Therefore, there is a necessity to adopt a systematic procedure for controlling quantum of pollutants emitted from each industry located in the area, in order to maintain the ambient air quality in and around the industries, within the safe limits. In so far as a particular pollutant is concerned, the relationship between the rate of emission of the pollutant discharged through the exist point of the chimney and the resulting concentration of the pollutant in atmospheric air at breathing level is to be evolved by using any ambient air quality model. The air quality survey would offer the necessary data for evolving the relationship between the emission rate and the resulting air concentration of a specific pollutant.

This relationship would necessarily be taken into account the following factors, namely: (1) Wind speed and wind direction prevailing in the area, and other meteorological parameters which are relevant to, the measurement of the atmospheric turbulence and the atmospheric mixing conditions that prevail, (ii) the height of exit point through which an industrial chimney discharges its emissions, and (iii) the velocity with which the emissions are discharged into the atmosphere through the chimney. This attempt, to correlate the pertinent parameters in a cause-effect relationship for describing the physical mechanism of dilution of pollutants in atmospheric air, is often referred to as modelling of air pollutant diffusion.

The atmospheric dispersion models are simulated mathematical systems of physics and chemistry that are governing the transport, dispersion and transformation of pollutants in the atmosphere. They are the indispensable tools for

prediction of air quality in the ever-expanding industrial environments. Several models are available for predicting air quality due to emission from multiple point sources. When applied for a specific industrial situation and prevailing ambient environmental conditions, performance evaluation of these models is much essential to asse**ss** their compatibility and accuracy. The reliability of the model must be assessed by applying the model to the historical meteorology**,** emissions and measured air quality of the specific industrial environment the US-EPA preferred ISCST3 model is one of the ambient air quality models, which over-predicted the 8 hr average SO_2 concentrations. The in discrepancies in predictions are assumed due to the assumption by the developers of ISCST3 that 10 min concentrations are equal to 60 min concentrations (Stiggins*et al.,* 2002; Wagas, *et al.,* 2003). Therefore, the ISCST3 predicted 8hrs concentrations are not 8 1 hr concentrations rather it is an average of 8 10 min concentrations. Alternatively, for a more compatible model to suit the Indian environmental conditions which are characterized with multiple point sources, a computer aided Gaussian model has been evolved to estimate the average ground level concentrations for user specified sampling period by using power law. This newly devised model is incarnated as multiple point source complex model-Average concentrations for the user specified sampling period (MPC-SP).

2. MATERIAL AND METHOD

The development of multiple point source complex model to estimate the average concentrations for the user specified sampling period (MPC-SP) model is based on the Gaussian dispersion equation. The basic features of the Gaussian dispersion equation were extensively described by (Turner, 1 967, 1994; ISI, 1978; DOEn, 1983).

2.1 Gaussian Dispersion Equation

Turner D.B (1994) presents the GDE selected for use in the model, which is

$$\chi(x,y,z;H)=\frac{Q}{2\pi\sigma_y\sigma_z\mu}\exp^*\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}. \quad (1)$$

The contribution to the total pollutant concentration at a particular source, with particular points at (x, y, z)

Where,

Q: the pollutant emission rate of the source, (□g/sec).

U: the mean wind speed at stack level, (m/sec).

□Y and □Z: the horizontal and vertical dispersion co-efficient respectively, (m).

H: the effective stack height, (m).

For computing Ground Level Concentrations (GLC), put Z=0 in equation (1), now the equation 1 reduces to

$$\chi(x,y,0,H)=\frac{Q}{\pi U\sigma_y\sigma_z}\exp\left(-\frac{y^2}{2\sigma_z{}^2}\right)\exp\left(-\frac{H^2}{2\sigma_z{}^2}\right) \quad (2)$$

For computing Ground Level Concentrations (GLC) along with the center-line of the plume (i.e. Y= O; Z = O) equation the 1 is reduced to

$$\chi_{(z,0,0,h)} = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left| -\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2 \right. \tag{3}$$

By using the above equations, 2 and 3, the model has been developed in C language for computing the short-term ground level concentrations and short-term ground level centre-line concentrations respectively. .

2.3 Model Parameterization

Development of the MPC-SP model is based on the Gaussian dispersion equation (GDE). This equation involves various parameters, such as wind speed at- stack heights, dispersion coefficients, and plume rise, etc. So many approaches are available for determining each of the above parameters. Each Air quality model utilizes separate equations for determining the parameter to predict the ground level concentrations (GLCs). The various parameters involved in the MPC-SP model, such as wind speed at stack height, downwind distance, cross wind distance, σ_Y, a_z, effective stack height, etc., are selected from the following approaches.

2.3.1 Wind Speed at Stack Height

The Power law is used to adjust the observed wind speed, u_{rof}, from a reference measurement height, $z_{f<(}$, to the stack or release height, h_t. The stack height wind speed, u_t, is used in the Gaussian plume equation (equations 1 to 3):

$$u_5 = u_{ref}\left(\frac{h_5}{z_{ref}}\right)^P$$

where p is the wind profile exponent. The MPC-SP model has been chosen the default values of ' p' as 0.12 for unstable stability conditions, u: 0.14 for neutral stability conditions and 0.24 for stable stability conditions.

2.3.2 Downwind and Crosswind Distances

The MPC-SP mode! is used a Cartesian receptor network. The analytical framework developed by Gifford (1959) for calculating the ground level downwind concentration is on the basis that the polluting source is a single stack. The extreme topmost left corner may be assumed as the user specified origin. Therefore, the user specified origin of (i,j) is shifted to the stack position by using the following mathematical formulas:

u = (i-spx) sin(-a) + (j-spy) cos (-a)

v = (i-spx) cosf-a)-(j-spy) sin (-a)

where spx and spy are the coordinates of the stack position with respect to i, j axis, respectively and a is angular wind direction for given angular wind direction (a), the relative distance (u,v) of the each $(i,j)^{th}$ grid on the downwind locations with respect to the stack positions are found out by the above mathematical formula. Therefore, the resultant represents the downwind distance (x) from the stack, and v represents the crosswind distance (y). For each $(i,j)^{lh\ value.}$ The corresponding relative distance x and y with respect to stack origin are known, this approach is used to determine the GLCs occasioned by an emission from a multiple point source.

2.3.3. Stability Class

Many a investigations, such as Pasquiil (1961) Turner (1964, 1994), Munn (1966) and Briggs (1973), have made

studies on classifying stability classes in the absence of any sophisticated observations. The meteorological conditions, defining Pasquiil turbulence types, have been suitably modified and it has been chosen for the present diffusion co-efficient the diffusion co-efficient is estimated through various approaches made by many researchers Smith (1951), Smith (1968) Pasquiil (1961, 1962, 1974), Gifford (1961), Turner (1964) Carpenter *et al.* (1971) and Briggs (1973). If the physical stack height is higher than 100 m, Briggs' interpolation schemes give better estimate. Therefore, Briggs' (1973) proposes a series of interpolation formulas that have been used in the Gaussian diffusion equations for estimating a_Y and a_z.

2.3.4 Plume Rise

Several investigators who have proposed formulae for the estimation of plume rise, are Briggs (1971, 1972), Guld Berg (1975), Montgomeny*et al.* (1972), Holland. Of all the formulae, the theoretical formula by Briggs (1971, 1972, 1975) yields the best results. Hence, this formula is used for estimating the plume rise.

2.3.5 Averaging Time

It is necessary to estimate concentrations from a single source for time intervals greater than a few minutes, the best estimate apparently can be obtained from (Turner, 1994) :

$$x_s = x_k \left(\frac{t_k}{t_s} \right)^p$$

where, x_s is desired concentration estimate for the sampling time, $X_{\%}$, x_k is concentration estimated for the shorter sampling time, t_k, p is between 0.17 and 0.20. The MPC-SP model has utilized the power law coefficient 'p' as 0.20.

2.4 Application of MPC-SP Model at ENNORE – MANALI North Chennai

The study region, North Chennai air basin is an industrial belt covering an area of about 10 x 10 km^2 with a flat terrain located close to Chennai metropolis, India. It houses a major Refinery, Petrochemical, Fertilizer and Chemical industries apart from Ennore Thermal Power Station (ETPS) and North Chennai Thermal Power Station (NCTPS) whose stack emissions contribute significantly to air pollution.

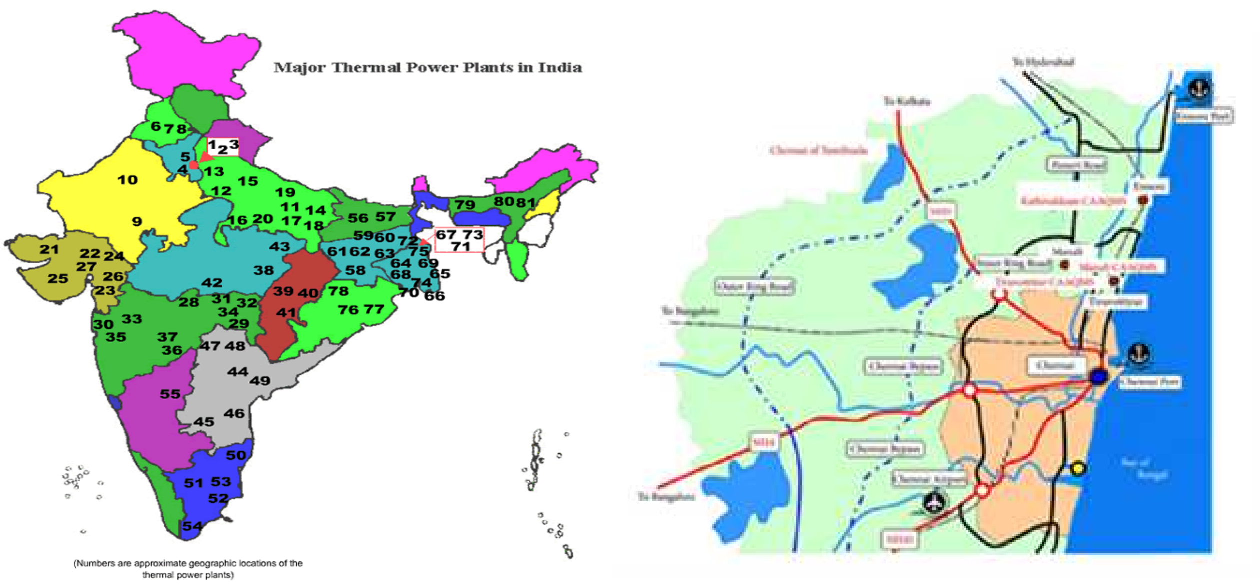

Figure 1: Description of the Study Area

2.4.1 Emission Inventory

The list of industries located in the study area was obtained from the State Pollution Control Board. The total number of industries identified within the study area was 277. Out of the 277 industries, only 37 large scale industries are letting emissions into the atmosphere, either through their process stacks or through their non-process sources such as DG Sets, boilers, etc. In the remaining 240 industries, 4 are large-scale proposed industries and the other 236 industries are small-scale industries, and they do not have any emission sources causing air pollution. The details such as stack height stack diameter, volume of flow, exit gas velocity, and stack-gas temperatures were documented after carrying out detailed emission inventory. It was ascertained that the stack height is varying from 10.0 m to 275.0 m, and the total discharge of SO2 emissions is in the order of 364.56 g/sec. A comprehensive survey was conducted for the collection of data relating to the geographical location of each stack (Latitude& Longitude) using GPS.

2.4.2 Meteorological and Ambient Air Quality Monitoring

The Tamil Nadu (State) Pollution Control Board is operating three Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in the North Chennai area. One continuous ambient air quality monitoring station is located at Manali, and another one at Kathivakkam, and the third one is at Tiruvottriyur. The data on concentration levels of Sulphur dioxide observed in the CAAQMS were obtained from the State Pollution Control Board. The meteorological data such as temperature, wind speed and wind direction were obtained from the Indian Meteorological Department for this study.

The MPC-SP model also requires input information on SO_2air quality data measured at North Chennai Air Basin for the same period. Such information is needed to test the performance of the MPC-SP model. The observed concentrations have been obtained from the three AAQ monitoring stations located on the downwind locations of the predominant wind direction in North Chennai. The sampling stations co-ordinates are denoted in Cartesian (X,Y) coordinates. In the Cartesian coordinate system, the X-axis is positive to the east and the Y-axis is positive to the north with respect to the user specified origin. The extreme top most left corner may be taken as the user specified origin.

2.5 MPC-SP Model Validation at North-Chennai Air Basin

The model MPC-SP is evaluated by comparison of the predicted GLCs of SO_2 for the period of 1 Year from 01-7-2011 to 30 -06-2012 with the measured SO_2 at the down-windThermal power plants at North Chennai The models output has been compared with the measured air quality data that indicate the calculated estimates have close agreement the measured air quality. The MPC-SP model has been used for prediction concentration of the pollutantSO_2 at the three sampling stations. These simulations are carried out for 3 sets of 8 .hourly meteorological data, which include various combinations of stability and wind speed, which may be possible during the whole say. The hourly SO_2 emissions are then considered.

2.6 RESULT AND DISCUSSIONS

The MPC-SP model was performed successfully for 12 months (July 2011 to June-2012) to predict the groundlevelconcentrations of SO2, emission from the 192 industrial stacks situated within the study area. Evaluation of performance of the model was ascertained, based on the outcome of the model results, by comparing the predicted concentrations with the observed concentrations of SO_2.

2.6.1 Evaluation of Model Performance

The measure of agreement developed by Wilmot is more appropriate for the investigation of model validation, where the observed and model-predicted values need to be compared **(Lei Ji et al., 2006).** In this study, the model performance was evaluated by comparing the predicted concentrations of SO2 in the model, with the observed (measured) concentrations in the 3 Continuous Ambient Air Quality Monitoring Stations located at Manali, Kathivakkam, and Tiruvottriyur within the Study Area, by considering the seasonal wind patterns. The statistical parameters namely the coefficient of correlation (r2), index agreement (d) as recommended by Willmott were used for the evaluation in the present study. The coefficient of correlation (r) represents the level of relation **(Rao et al., 1985).** The Index agreement provides the degree to which the model predictions are error-free **(Banerjee et al., 2011).** Figure 2-13 shows scatter-plots for the observed (measured) SO_2 concentrations in the Continuous Ambient Air Quality Monitoring Stations (CAAQMS), and the predicted SO_2 concentrations in the downwind receptor locations in the MPC-SP model.

Figure 2-13 shows scatter–plots for the measured SO_2 concentrations and the predicted SO_2 concentrations in the downwind receptor locations in the MPC-SP model, applicable to North Chennai Air Basin.

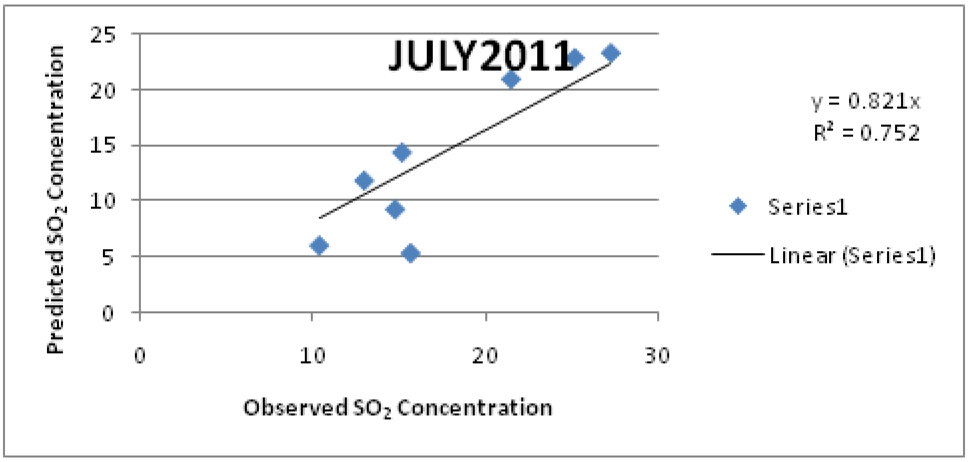

Figure 2: Scatter–Plots for the Observed SO_2 Concentrations vs Predictedso$_2$ Concentrations of July 2011

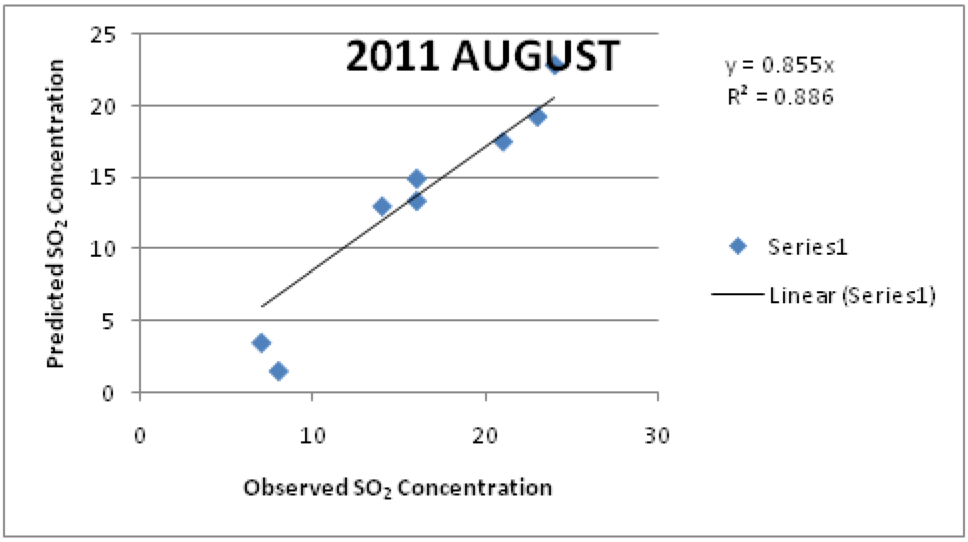

Figure 3: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of August 2011

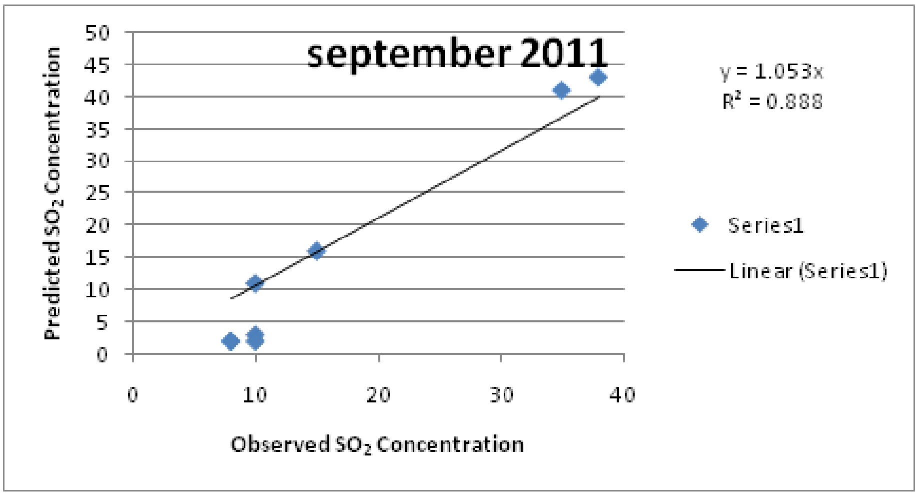

Figure 4: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of September 2011

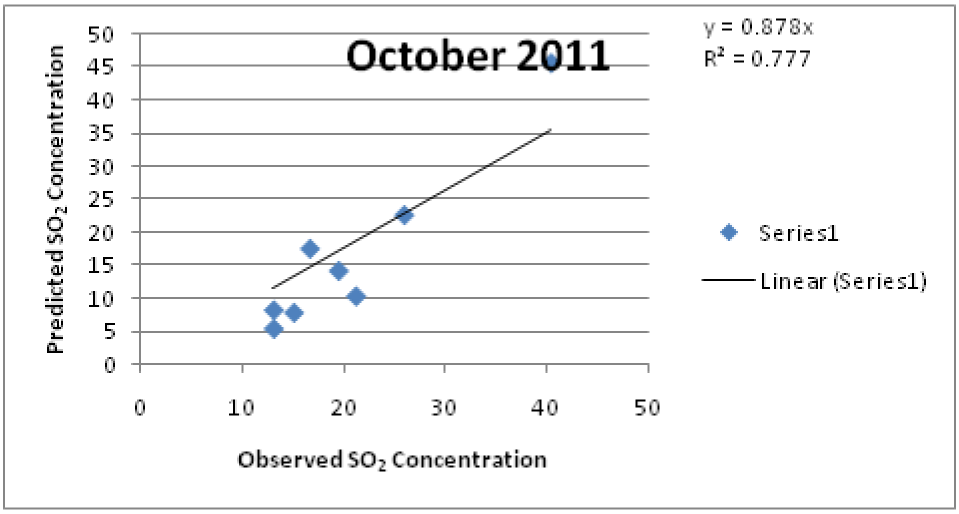

Figure 5: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of October 2011

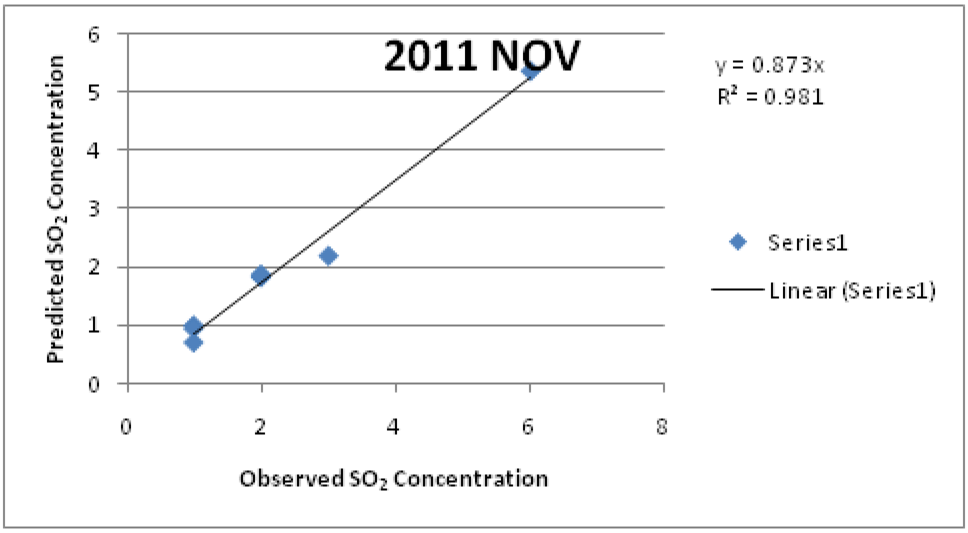

Figure 6: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of November 2011

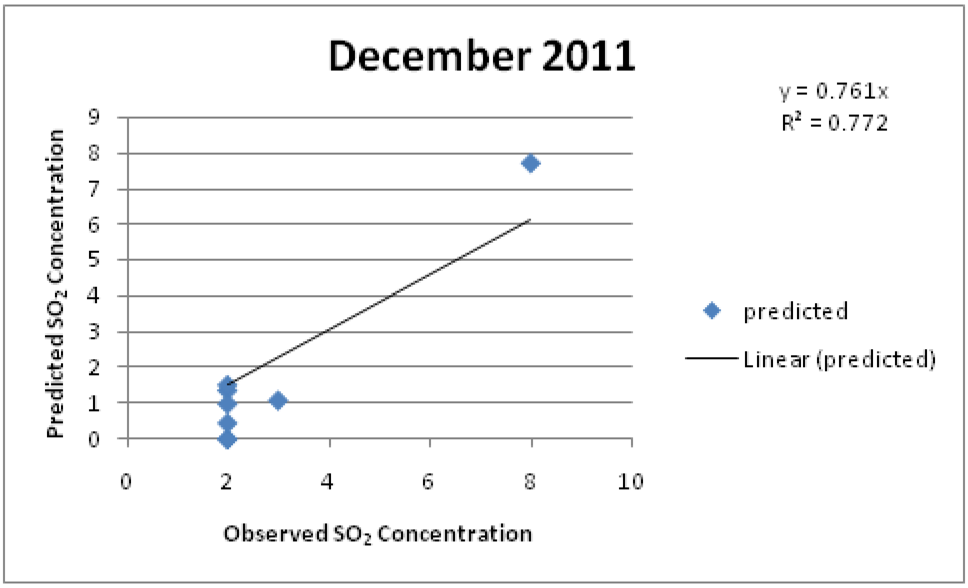

Figure 7: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of December 2011

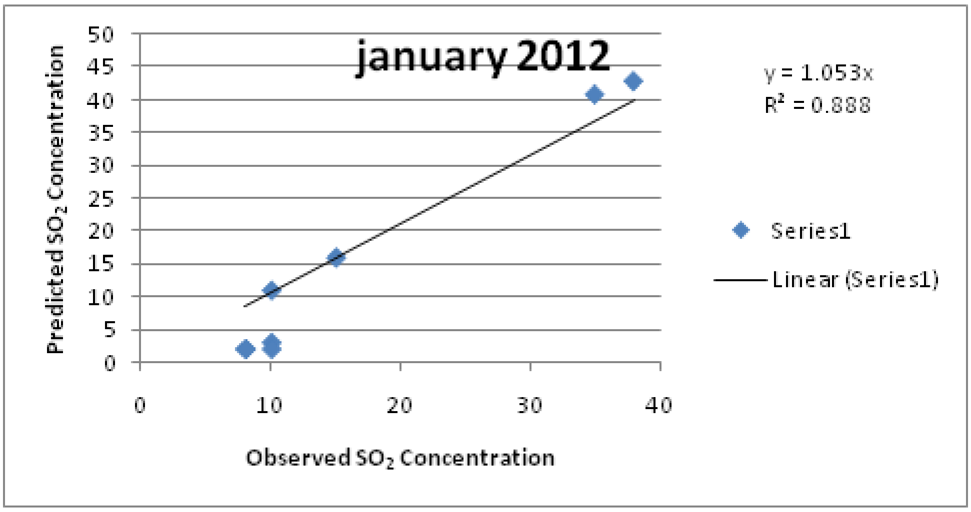

Figure 8: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of January 2012

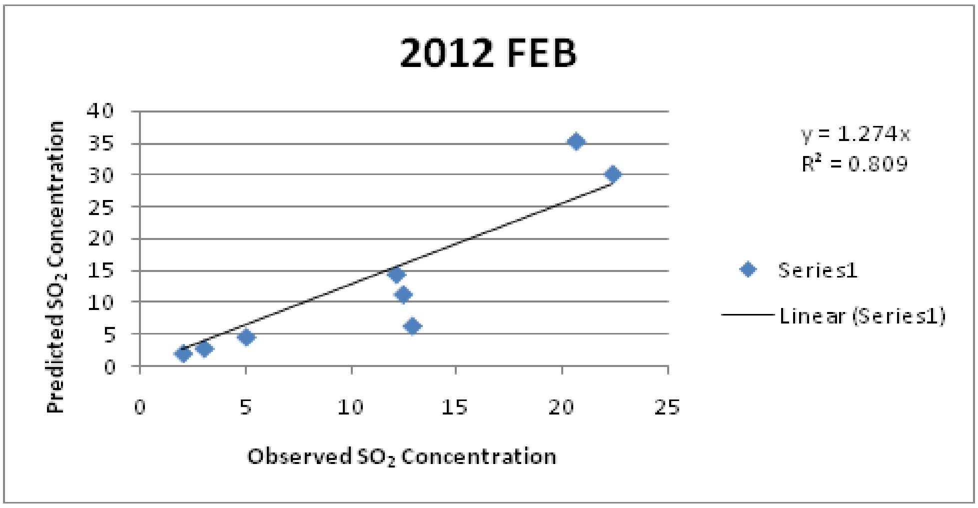

Figure 9: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of February 2012

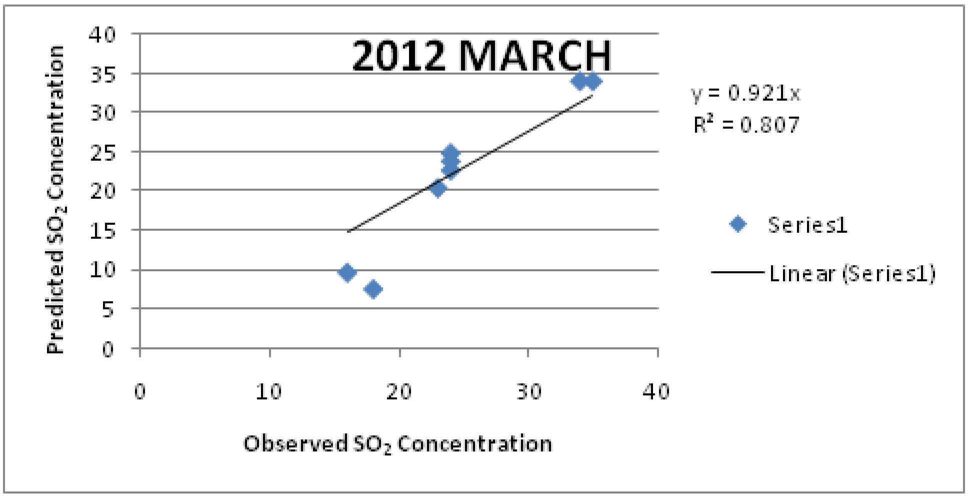

Figure 10: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of March 2012

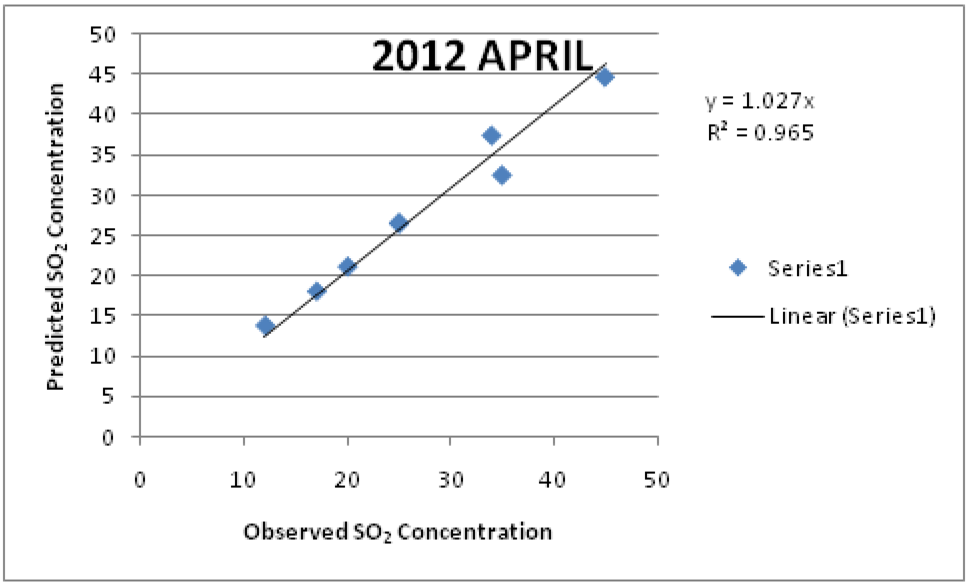

Figure 11: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of April 2012

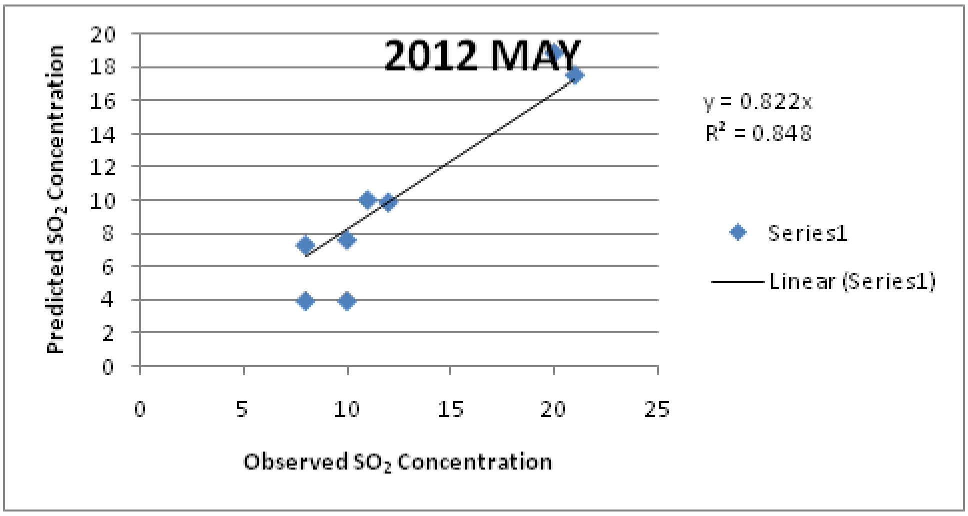

Figure 12: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of May 2012

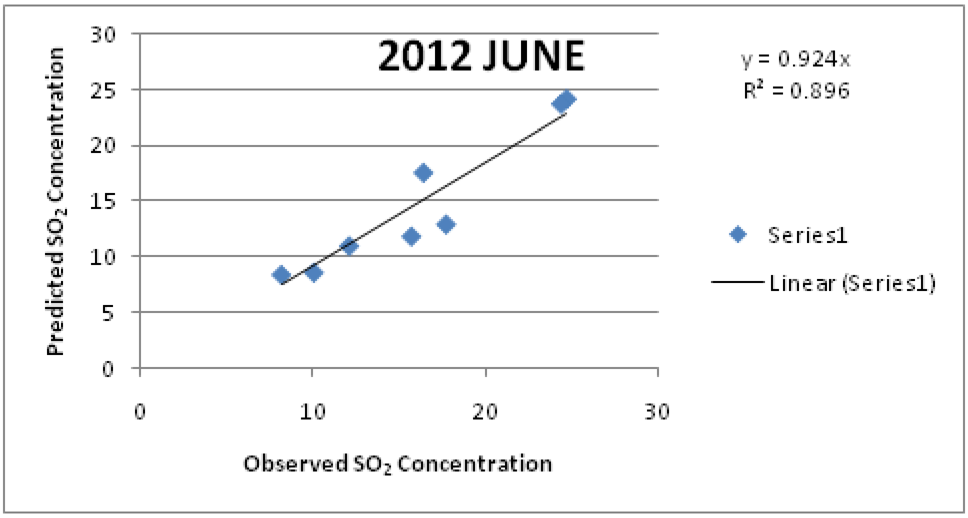

Figure 13: Scatter–Plots for the Observed SO2 Concentrations vs Predicted SO2 Concentrations of June 2012

CONCLUSIONS

The MPC-SP model was performed successfully for 12 months (July 2011 to June-2012) to predict the ground level concentrations of SO_2, emission from the 192 industrial stacks situated within the study area. Evaluation of performance of the model was ascertained, based on the outcome of the model results, by comparing the predicted concentrations with the observed concentrations of SO_2.

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